Baryonic contributions to e^+e^- yields in a hydrodynamic model of Pb+Au collisions at the SPS

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We analyze e^+e^- yields from matter containing baryons in addition to mesons using a hydrodynamic approach to describe Pb+Au collisions at 158 A GeV/c. We use two distinctly different e^+e^- production rates to provide contrast. Although the presence of baryons leads to significant enhancement of e^+e^- emission relative to that from mesons-only matter, the calculated results fall below the data in the range $400 < M_{e^+e^-}/\text{MeV} < 600$. The calculated results are, however, only 1.3–1.5 standard deviations below the data, which may not be statistically significant.

1. Theoretical Approach

The observation of low-mass dielectron excess over conventional sources by the CERES collaboration [1,2] has spurred considerable theoretical activity. In addition to the microscopic production rates, confrontation of theory with data requires a description of the space-time evolution of the produced matter. We have used a one-fluid hydrodynamical description, which is constrained to reproduce the measured hadron spectra [3]. The initial state of the hydrodynamic evolution, which is assumed to be sufficiently thermalized, is parametrized to reproduce both the baryonic and mesonic components. The adiabatic expansion is then governed by the laws of hydrodynamics (including baryon number and strangeness conservation) and the input equation of state (EOS). In the calculations reported here, the EOS admits a phase transition to the quark-gluon plasma at a critical temperature $T_c = 200$ MeV. The hadronic part of the EOS includes particles and resonances up to 2 GeV. The system is assumed to maintain both local thermal and chemical equilibrium until freeze-out. The freeze-out criterion employed, energy density $\epsilon_f = 0.15$ GeV/fm^3, corresponds to an average freeze-out temperature of $T_f = 140$ MeV. Admissible changes in both T_c and T_f do not affect our conclusions (see [4]).

We use e^+e^- production rates from the calculations of Steele, Yamagishi and Zahed (hereafter SYZ [5])and Rapp, Urban, Buballa and Wambach (hereafter RUBW [6]). SYZ use experimentally extracted spectral functions and on-shell chiral reduction formulas coupled with a virial expansion scheme. For baryon number density $n_b = 0$, these rates reproduce those of Gale and Lichard [7]. The RUBW rates are based on a many-body approach, in which phenomenological interactions are used to calculate the ρ-meson spectral function in matter containing baryons. These two rates represent contrast both in
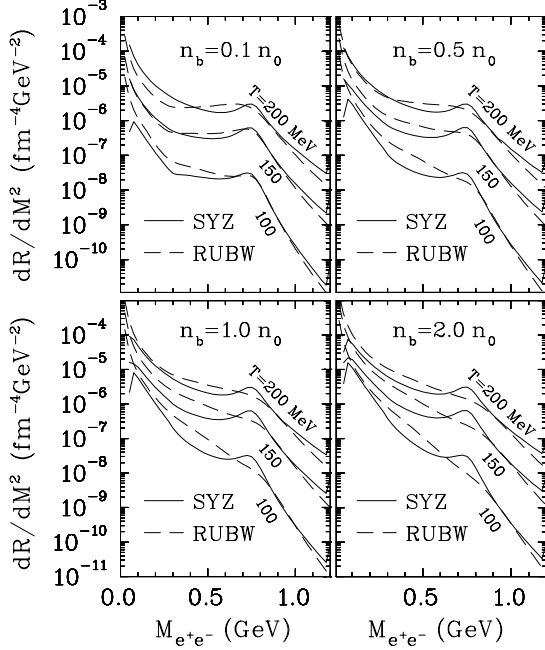
Figure 1. The e^+e^- production rates at different temperatures and baryon densities versus pair invariant dielectron mass. The solid (dashed) lines are results from Steele, Yamagishi, and Zahed (SYZ) (Rapp, Urban, Buballa, and Wambach (RUBW)).
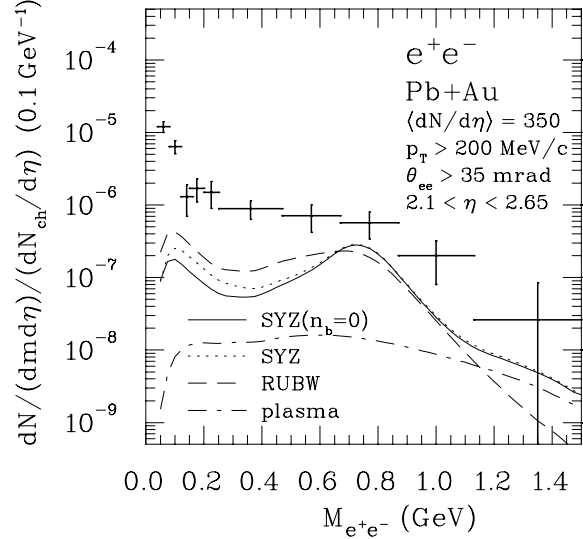

Figure 2. Dielectron yields from the hadronic part and plasma part of the fireball. Solid lines are results for matter without baryons with the SYZ rates. Also shown are results in matter with baryons (short-dashed lines: SYZ rates; long-dashed lines: RUBW rates). Kinematic cuts and detector resolution are incorporated. The data shown are preliminary [8].

terms of their input physics and the theoretical techniques employed. They also differ significantly in their absolute magnitudes (see Fig. 1). The distinguishing features of the SYZ rates are: (1) Enhancements relative to the baryon-free case are of order 2-3 and are restricted to $M_{e^+e^-}/\text{MeV} < 500$. (2) The prominent signature at the ρ-meson vacuum mass persists at nearly all values of T and n_b. In contrast to SYZ, the two most striking features of the RUBW results are: (1) Rates are significantly larger than those of SYZ in the range $200 < M_{e^+e^-}/\text{MeV} < 600$. (2) The tell-tale signature at the ρ-meson vacuum mass is weakened, predominantly with increasing n_b.

2. Results

In Fig. 2, we show the results of dielectrons radiated during the lifetime of the fireball. These results are folded with the cuts and resolution of CERES. Our calculation is tuned to reproduce the hadronic results of NA49 and yields an average multiplicity of $\langle dN_{ch}/d\eta \rangle \cong$ 330 within the CERES acceptance region. The CERES collaboration finds both the shape of the spectrum and the yield scaled with multiplicity to vary with multiplicity [2]. We
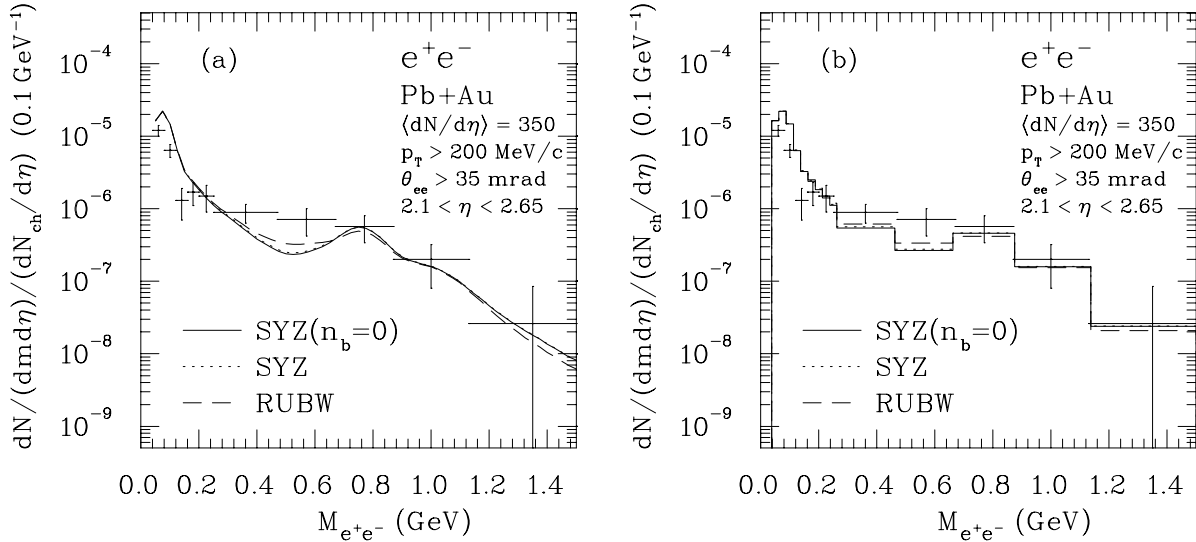
Figure 3. (a) Calculated total dielectron mass spectra compared with preliminary data [8]. Solid lines are results for matter without baryons with the SYZ rates. Also shown are results in matter with baryons (short-dashed lines: SYZ rates; long-dashed lines: RUBW rates) . Kinematic cuts and detector resolution are incorporated. (b) Like (a), but the calculated results employ bins to contrast with those used by CERES.

have therefore opted to compare our results with the preliminary data [8] from nearly central collisions with $\langle dN_{ch}/d\eta \rangle = 350$.

The contribution from the quark-gluon plasma is about an order of magnitude below the hadronic contributions. The SYZ rates with baryons are about a factor of 2 larger than those without baryons, but mostly below $M_{e^+e^-} = 400$ MeV. This translates to an enhancement of about a factor of two or less relative to the baryon-free case. The larger rates of RUBW result in enhancements of the thermal yield, even up to $M_{e^+e^-} = 300-600$ MeV, by a factor of about three relative to those in mesons-only matter.

In addition to thermal pairs, the measured yield contains contributions from meson decays after freeze-out. This background was calculated from the distributions and abundances of hadrons at freeze-out given by our calculations. The only exception is the ϕ-yield, which is suppressed by a factor 0.6 to achieve consistency with the data [9]. The resulting background is in agreement with the background estimated by the CERES collaboration.

The total yield (sum of the thermal and background contributions) is presented Fig. 3(a). Results for the SYZ rates with and without baryons are virtually indistinguishable from each other, despite significant enhancements in the microscopic rates for $M_{e^+e^-} < 400$ MeV. In this mass region, the Dalitz decay backgrounds are an order of magnitude larger than the thermal yields and entirely mask the baryonic contributions. The RUBW microscopic rates, being larger than those of SYZ in the region below the ρ-mass, lead

to total yields that are somewhat distinguishable from the case without baryons, but lie below the data roughly by a factor of two.

It is instructive to bin the calculated results to contrast with the bins used by the CERES collaboration (see Fig. 3(b)). The calculated spectra fall below the data at only two points. At $M = 360$ MeV, the results are close to the experimental lower limit. At $M = 570$ MeV, the difference between the data and the calculated result is only about 1.5 standard deviations for the SYZ rates with and without baryonic contributions, whereas the use of the RUBW rates leads to an yield which is 1.3 standard deviations below the data. Given the uncertainties, these differences may not be statistically significant. We thus conclude that thermal production of electron pairs may well be large enough to account for the observed enhancement.

3. Summary

We have calculated e^+e^- emission in Pb+Au collisions at 158 AGeV/c using two different dielectron production rates within the framework of hydrodynamics. The rates calculated by SYZ include baryonic contributions arising from pion-nucleon interactions and those of RUBW account for additional in-medium modifications, which leads to a substantial broadening of the ρ-meson spectral function. We found that the additional contributions due to baryons in the rates of SYZ give modest contributions, but mainly at low values of invariant mass where the spectrum is dominated by background decays. The final dielectron spectra with and without baryonic contributions are thus almost identical. On the other hand, the larger ρ-width in the rates of RUBW leads to comparatively larger yields in the 300–600 MeV mass region. In all cases, the calculated results are below the data, but the differences are not large to indicate statistical significance. The yield of thermal dielectrons appears to be large enough to explain the preliminary data.

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